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# Feasibility of Using Satellite Imagery in ADES

Prepared for the

Transportation Development Centre
Policy and Coordination Group
Transport Canada

by

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September 1990

460584

91-03667/

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

Transport Canada / Transports Canada

# PUBLICATION DATA FORM

| 1. Transport Canada Publication No. | 2. Project No. | 3. Recipient's Catalogue No. |
|---|---|---|
| TP 10651E | 7522/3/4 | |

| 4. Title and Subtitle | 5. Publication Date |
|---|---|
| Feasibility of Using Satellite Imagery in ADES | September 1990 |
| | 6. Performing Organization Document No. |

| 7. Author(s) | 8. Transport Canada File No. |
|---|---|
| J.A. Ostrowski and D.N.H. Horler | 1455-177-4 |

| 9. Performing Organization Name and Address | 10. DSS File No. |
|---|---|
| Horler Information Inc.<br>Suite 704, 116 Albert Street<br>Ottawa, Ontario<br>K1P 5G3 | 11. DSS or Transport Canada Contract No.<br>T8200-9-9582/01-XSD |

| 12. Sponsoring Agency Name and Address | 13. Type of Publication and Period Covered |
|---|---|
| Transportation Development Centre<br>200 Rene Levesque Blvd West<br>Suite 601, West Tower<br>Montreal, Quebec<br>H2Z 1X4 | Final Report |
| | 14. Project Officer<br>B. B. Myers |

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract


Transport Canada's Airspace Design Expert System (ADES) requires a detailed Digital Elevation Model (DEM), which can potentially be provided by SPOT (Système Probatoire d'Observation de la Terre) stereo satellite imagery. The purpose of the project was to test the use of SPOT imagery in ADES.

A terrain database was generated from stereo SPOT imagery in the National Capital Region. Horler Information's proprietary software system, *HI-VIEW*, was used for the DEM generation. The DEM was supplied to Transport Canada as DTED (Digital Terrain Elevation Data) Level 1 and Level 2 files.

It was confirmed that the data supported the preparation of a contour map, 3-D terrain views and flight simulations in ADES. Enhancements to ADES software are probably required to handle DTED Level 2 data.

SPOT-derived DEMs and images have the potential to provide photo-realistic terrain views by draping the imagery over the DEM in oblique or perspective views. Enhancements to ADES would be needed to support such functions. SPOT imagery can also provide land cover classification.

A dedicated image processing workstation could be used to prepare terrain databases for ADES.


| 17. Key Words | 18. Distribution Statement |
|---|---|
| Digital terrain model, satellite imagery, airspace design | Limited number of copies available from the Transportation Development Centre on request. |

| 19. Security Classification (of this publication) | 20. Security Classification (of this page) | 21. Declassification (date) | 22. No. of Pages | 23. Price |
|---|---|---|---|---|
| Unclassified | Unclassified | | xii,20 | |

TDC/CDT 79-005
Rev 88



Canada

Transports Canada Transport Canada

# FORMULE DE DONNÉES POUR PUBLICATION

| 1. N° de la publication de Transports Canada | 2. N° de l'étude | 3. N° de catalogue du destinataire |
|---|---|---|
| TP 10651E | 7522/3/4 | |

| 4. Titre et sous-titre | 5. Date de la publication |
|---|---|
| Feasibility of Using Satellite Imagery in ADES | septembre 1990 |
| | 6. N° du document de l'organisme exécutant |

| 7. Auteur(s) | 8. N° de dossier — Transports Canada |
|---|---|
| J.A. Ostrowski et D.N.H. Horler | 1455-177-4 |

| 9. Nom et adresse de l'organisme exécutant | 10. N° de dossier — ASC |
|---|---|
| Horler Information Inc.<br>116, rue Albert, pièce 704<br>Ottawa (Ontario)<br>K1P 5G3 | 11. N° de contrat — ASC ou Transports Canada<br>T8200-9-9582/01-XSD |

| 12. Nom et adresse de l'organisme parrain | 13. Genre de publication et période visée |
|---|---|
| Centre de développement des transports<br>200, boul. René Lévesque ouest<br>pièce 601, tour ouest<br>Montréal (PQ)<br>H2Z 1X4 | rapport final |
| | 14. Agent de projet<br>B. B. Myers |

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)

16. Résumé


Le système expert d'aménagement de l'espace aérien (ADES) que Transports Canada est en train d'élaborer nécessite un modèle numérique d'élevation, et l'idée a été lancée d'utiliser pour cela l'imagerie stéréoscopique fournie par le satellite SPOT (Système probatoire d'observation de la terre). La présente recherche a eu pour objet de vérifier la faisabilité de cette idée.

L'imagerie stéréoscopique fournie par le satellite SPOT et couvrant la région de la capitale nationale a servi de base de données cartographiques pour la production d'un modèle numérique d'élevation grâce au logiciel *HI-VIEW* de la firme Horler Information. Le modèle numérique a été remis à Transports Canada sous forme de bases de données altimétriques de niveaux 1 et 2.

La recherche a montré que la base de données permet la saisie de cartes de courbes de niveau, la visualisation topographique tridimensionnelle et la simulation de trajectoires d'approche par le système ADES. Pour ce qui est du modèle niveau 2, un logiciel ADES plus puissant sera probablement nécessaire.

Il est en principe possible d'obtenir des vues cartographiques réalistes en projections obliques ou perspectives en surimposant l'imagerie fournie par le satellite SPOT sur celle du modèle numérisé. Les fonctions correspondantes nécessiteront un renforcement du système ADES. L'imagerie fournie par le satellite SPOT permet en outre la classification des occupations du sol.

Un poste de travail graphique dédié associé au système ADES pourrait servir à l'élaboration de bases de données topographiques.


| 17. Mots clés | 18. Diffusion |
|---|---|
| Modèle numérique d'élevation, imagerie satellitaire, aménagement de l'espace aérien. | Le Centre de développement des transports dispose d'un nombre limité d'exemplaires. |

| 19. Classification de sécurité (de cette publication) | 20. Classification de sécurité (de cette page) | 21. Déclassification (date) | 22. Nombre de pages | 23. Prix |
|---|---|---|---|---|
| Non classifiée | Non classifiée | | xii,20 | |

CDT/TDC 79-005
Rev 88



Canada

## Project Team

The project was carried out by a team of Horler Information Inc. personnel. Mr J.A. Ostrowski, M.Sc., was the Project Leader with prime responsibility for the technical work. Dr D.N.H. Horler was responsible for contract management. Computer systems support was provided by Mr B.D. Wasson, M.Sc., and administrative support by Ms. J.L Danks.


## Acknowledgements

Horler Information Inc. wishes to acknowledge the assistance afforded by Mr J.C. Ainsworth, Aeronautical Information Services, Transport Canada, and by Mr B.B. Myers, Transportation Development Centre, Transport Canada.

## Summary

Transport Canada is developing an Airspace Design Expert System (ADES) for designing instrument approach airways in a 3-D computer graphics environment. ADES requires as part of its database a detailed Digital Elevation Model (DEM), for which data from military sources are currently used. The availability of SPOT (Système Probatoire d'Observation de la Terre) stereo satellite imagery offers an alternative data source and makes it possible to obtain accurate elevation data as well as land cover information. The purpose of the project was to test this concept.

A terrain database was generated from stereo SPOT imagery in the National Capital Region. Horler Information's proprietary software system, *HI-VIEW*, was used for the DEM generation. The process required data preprocessing, stereo image matching, editing, formatting, transfer to ADES, and verification and testing within ADES. The DEM was supplied to Transport Canada as DTED Level 1 and Level 2 files.

The standard deviation of the difference between the Level 2 DEM and 349 elevation control points read from 1: 25,000 scale topographic maps was 11.1 metres, equivalent to about one-third of a pixel. The Level 1 DEM was generated from the Level 2 file by averaging pixels.

It was confirmed that the Level 1 data supported the preparation of a contour map, 3-D terrain views and flight simulations in ADES. The data volume of the Level 2 data have so far prevented their evaluation on ADES. Enhancements to ADES software are probably required to handle DTED Level 2 data.

SPOT-derived DEMs and images have the potential to provide photo-realistic terrain views by draping the imagery over the DEM in oblique or perspective views. ADES presently does not have capabilities for raster image manipulation and display; the incorporation of such functionality would probably be feasible for static images but not for animations because of the data volume involved.

SPOT imagery can support a polygonal (as opposed to a raster) database by enabling the classification of land cover types, from which polygon outlines or

other features can be extracted.

A dedicated image processing workstation could be used to prepare terrain databases for ADES. It would be able to generate DEMs and carry out a range of other functions. The system would be a companion system to ADES and should ideally be networked to it.

**Sommaire**

Le système expert d'aménagement de l'espace aérien (ADES) que Transports Canada est en train d'élaborer doit pouvoir servir à la définition de trajectoires d'approche aux instruments par des techniques infographiques tridimensionnelles. Le modèle numérique d'élevation qui fait partie de la base de données du système ADES a été édifié à partir de données provenant de sources militaires. L'imagerie stéréoscopique fournie par le satellite SPOT (Système probatoire d'observation de la terre) pourrait devenir une autre source de données précises pour l'obtention de cartes topographiques détaillées. La présente recherche a eu pour but de vérifier la faisabilité de cette idée.

L'imagerie stéréoscopique fournie par le satellite SPOT et couvrant la région de la capitale nationale a servi de base de données cartographiques pour la production d'un modèle numérique d'élevation grâce au logiciel *HI-VIEW* de Horler Information. Le procédé utilisé nécessite plusieurs étapes: prétraitement, restitution stéréoscopique, correction, mise en forme, transfert au système ADES, vérification et essais post-transfert. Le modèle numérique a été remis à Transports Canada sous forme de bases de données de niveaux 1 et 2.

L'écart type de la différence entre les données altimétriques tirées du modèle niveau 2 et 349 points de contrôle sélectionnés sur des cartes topographiques à l'échelle de 1:25 000 a été de 11,1 m, soit l'équivalent d'à peu près un tiers de pixel. Le modèle niveau 1 est constitué de données formées par l'opération de la moyenne des pixels contenus dans le modèle niveau 2.

La recherche a montré que le modèle niveau 1 permet la saisie de cartes de courbes de niveau, la visualisation topographique tridimensionnelle et la simulation de trajectoires d'approche par le système ADES. Pour ce qui est du modèle niveau 2, la grande quantité de données qui le composent rend impossible pour le moment leur évaluation sur ADES. Un logiciel ADES plus puissant sera probablement nécessaire.

Il est en principe possible d'obtenir des vues cartographiques réalistes en projections obliques ou perspectives en surimposant l'imagerie fournie par le satellite SPOT sur celle du modèle numérisé. Mais le système ADES ne se prête pas pour le moment à la manipulation et à la visualisation de l'imagerie

ligne par ligne, fonction qu'il sera possible d'intégrer s'il s'agit d'images statiques, mais non pour des images animées qui exigent la manipulation d'une trop grande quantité de données.

L'imagerie SPOT peut effectivement servir de support à une base de données topographiques utilisant une définition polygonale, par opposition à un traitement ligne par ligne, du sol survolé, ceci en vertu de la possibilité de classement des occupations du sol d'où il est possible d'extraire des polygones et d'autres détails utiles.

Un poste de travail graphique dédié associé au système ADES pourrait servir à l'élaboration de bases de données topographiques, notamment en produisant des modèles numérisés, et lui être relié par un réseau local pour en faire un système complet.

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## Glossary of Abbreviations, Acronyms and Symbols

| | |
|---|---|
| 3-D | Three Dimensional |
| ADES | Airspace Design Expert System |
| DEM | Digital Elevation Model |
| DMA | United States Defence Mapping Agency |
| DNs | Digital Numbers |
| DTED | Digital Terrain Elevation Data |
| ECP | Elevation Control Point |
| GCP | Ground Control Point |
| NATO | North Atlantic Treaty Organization |
| NTS | National Topographic System |
| SPOT | Système Probatoire d'Observation de la Terre |
| UTM | Universal Transverse Mercator |

# 1 Introduction

Aircraft fly on predetermined flight paths from take-off to landing; the number of these flight paths is increasing and will become more varied through the introduction of new guidance and navigation facilities. En-route corridors and airport approaches are designed based on criteria which specify the method, allowable tolerances, units of measurement and accuracies for the various phases of an aircraft's itinerary. Designs are prepared manually from charts of various scales, templates, aerodrome site plans and other inputs.

Sophisticated computer graphics design can aid the preparation of the flight path designs. An experimental study development has demonstrated that such a technique can be cost-effective and reverse the trend to increased human resources for the expanding workload. The experimental system enables an inexperienced computer user to design an instrument approach airway in a 3-D environment. The experimental system is being further developed to provide a Canada-wide capability that will enable the regional inspectors responsible for airspace design to continue to do their work efficiently even when the rule base is substantially changed. The developing system is called the Airspace Design Expert System (ADES).

ADES requires as part of its database a detailed Digital Elevation Model (DEM) to provide the necessary information on terrain throughout Canada. The current approach is to use the data available through military sources, specifically Digital Terrain Elevation Data (DTED) from the United States Defence Mapping Agency (DMA). Three sets of files are used for the ADES terrain model. These are the DTED files, the contour files and the 3-D files. The contour files and the 3-D files are generated from the DTED. The DTED presently used in the ADES is a DEM with points spaced every 3 seconds in both latitude and longitude (about every 90 metres N-S and 65 metres E-W at the latitude of Ottawa). The DEM on the latitude/longitude grid is used for terrain modelling to calculate the elevation of any given point, draw a contour map, and simulate 3-D views and animations.

The elevation data used in ADES suffer from the limitations of a fairly coarse spatial resolution and an inability to generate realistic terrain views.

It is becoming feasible with the availability of the spectacularly detailed SPOT (Système Probatoire d'Observation de la Terre) imagery to use satellite data and digital processing to obtain improved elevation data. Furthermore, these data take into account vegetation cover, in particular the trees, and buildings and other man made objects. These data are more appropriate than the mapped terrain data for ADES. This project is intended to explore the feasibility of using such satellite imagery.

Horler Information Inc. has developed a system for producing DEMs from stereo satellite image pairs. Either SPOT or Landsat satellite data can be used. The system is based on automatic stereo-correlation to extract the DEM from the imagery, a process which is very much faster and less expensive than traditional methods of creating DEMs. The absolute DEM accuracy and

resolution from SPOT data are both about 10 metres. The DEM can be used to create oblique views of terrain and may be draped with the original imagery to create photo-realistic visual scene simulations.

The use of satellite imagery and satellite-derived DEMs has the potential to enhance ADES by

1. providing up to date terrain elevation data virtually on demand. Stereo SPOT coverage of large parts of Canada already exists and the archive is constantly expanding;
2. providing imagery showing actual land cover, including urban and populated areas;
3. enabling realistic visual simulations of approaches to be created.

The present project was a proof of concept study to generate a terrain database in the vicinity of a selected airport. The database consists primarily of a SPOT-derived DEM. The feasibility was also assessed of incorporating and utilizing other satellite image-derived products, such as land cover classification and true colour imagery. These data types would enable points 2 and 3 above to be implemented, but would require additions to the ADES database structure and software. Data management issues concerning a relatively high resolution DEM are critical (e.g., computation times, disk and memory size requirements).

The objective of the project was thus to compare and evaluate digital terrain elevation data obtained from satellite-derived imagery with DTED obtained from conventional optical scanning of topographic maps.

## 2 Description of Work Carried Out

The work consisted of the following tasks:

1 Terrain database generation

The requirement was to generate a terrain database from existing SPOT image stereo pairs in the general Ottawa area of approximately 20km x 6km or an equivalent area as mutually agreed. In fact, two DEMs at different resolutions (about 30 m and 90 m) of an area approximately 25 km x 25 km were prepared and delivered. The area, shown in Figure 1, includes the Gatineau Airport, Rockliffe Airfield, and Ottawa International Airport.

2 Data formatting

The data were formatted to correspond to the format used in ADES. This required conversion to the latitude/longitude grid in a format based on the NATO DTED format;

3 Database loading into ADES

The DEM was loaded into ADES, and used to build a sample terrain database.

4 Database verification and demonstration

It was confirmed that the database supports the preparation of a contour map, a 3-D terrain view and a simulated airport approach, within the ADES equipment operated by Transport Canada.

5 Feasibility evaluation

The feasibility was assessed of using of SPOT imagery within ADES to provide real terrain with land cover.

6 Final reporting

This final report describing the work done and the tests made was prepared in accordance with the requirements of the contract.

Figure 1 DEM area

# 3 Technical Description of DEM Generation

## 3.1 Satellite data

The data used for derivation of the DEM consisted of two SPOT panchromatic images of the Ottawa area, previously acquired at the request of Horler Information. Both scenes were imaged from the west. The first image was recorded on 5 August 1987 at a viewing angle of 28.27 degrees from vertical, and the second image was acquired on 11 August 1987 at an angle of 7.31 degrees. The base to height ratio for such an arrangement was about 0.4, *i.e.*, for every metre of elevation there would be 0.4 m of parallax difference between a pixel position in the two images.

The two images were practically cloud free. Typical of SPOT images of mid-latitude vegetated terrain, both images were quite dark, with most of the radiance values in the range of about 30 digital numbers (DNs).

## 3.2 Data preprocessing

The original images were not geometrically corrected. Horler Information performs its own geometric correction step after preprocessing the Ground Control Point (GCP) positions to preserve the parallax signal in the corrected images.

After the geometric correction step, the 3072 x 3072 pixel subscene (10 m pixels) for DEM generation was selected. The coordinates of the scene corners were as follows

| | |
|---|---|
| - Upper Left corner, lat/long: | 75.884573W, 45.590557N |
| - Upper Left corner, zone 18 UTM: | 431,000E, 5,048,720N; |
| | |
| - Lower Right corner, lat/long: | 75.488374W, 45.316419N |
| - Lower Right corner, zone 18 UTM: | 461,720E, 5,018,000N. |

The selected scene extended as far south as possible, to include most of the urban area of Ottawa and the surrounding cities, as well as the Ottawa International Airport. There were some missing data in the southwest and southeast corners of the scene because of the slant of the satellite track.

The next preprocessing step consisted of reducing the size of the two images to 1024 x 1024 pixels, by averaging the DN values in a 3x3 window. The pixel size of the resulting images was thus 30 m. The final step involved the histogram equalization of the images. This filling of the full range of the DN values, 0 to 255, is necessary to provide a stronger signal for the stereo image matching.

## 3.3 Digital Elevation Model generation

At Horler Information, a DEM is derived automatically using our proprietary software system, *HI-VIEW*. The process essentially involves the digital matching of the homologous pixels of a stereo image pair and determining their relative parallax. The differential parallaxes are then converted into elevations using knowledge of the viewing geometry. The "raw" DEM generated by the computer process is then edited to remove errors, using a combination of manual and automated techniques, as described below.

## 3.4 Digital Elevation Model editing

DEM editing involved several steps, described in the following sections. The editing took approximately two weeks because of the unexpected phenomenon of the "steps" (Section 3.4.2) and the need to develop software tools as we went along. With the appropriate tools available, we estimate that the editing time would be one to two days.

### 3.4.1 *Visual DEM verification and blunder removal*

The automatic DEM generation process includes an automatic blunder detection and removal step. However, there is a small fraction of blunders that are not detected by this approach. These blunders usually occur over water and in other featureless areas. Therefore it is necessary to inspect the raw DEM visually and to remove the remaining blunders, which are easily identified. Blunder removal consists of flagging rectangular areas covering blunders as null areas, and then interpolating across all null areas in the DEM. The manually determined blunder areas occurred mostly over the Ottawa and Gatineau Rivers and some of the lakes.

### 3.4.2 *Elevation step editing*

The raw DEM contained two lines crossing the area at about 17 degrees from the vertical. Across each of the lines there was a discontinuity in elevation, from lower value on the west side to higher value on the east side of each line. We hypothesize that this effect is due to shifts of the SPOT sensor arrays; however, for the purpose of the current project, our concern was only to remove the "step" distortion from the final DEM.

The elevation step editing process consisted of determining the exact position of the steps, determining their amplitude which was about 20 m, and finally removing them. The process was empirical and essentially resulted in tilting the affected part of the DEM by applying local linear corrections.

### 3.4.3 *Elevation Control Point acquisition*

An important step in the DEM derivation is its verification against known elevations. Of course, to do a full verification, a DEM of the same resolution and higher accuracy would be needed - thus defeating the purpose of deriving the new DEM in the first place. So, realistically, the verification has to be restricted to a limited number of isolated points, termed here Elevation Control Points (ECPs).

To achieve the maximum possible accuracy of the DEM verification, we acquired 349 ECPs from the 1:25,000 NTS map sheets of the area. Most of the points were all the available benchmark elevations, so their values were accurate; the only possible error was due to the measurement of an ECP position. However, since most of the benchmark elevations are marked on relatively flat areas, this source of error is probably not significant. In some areas, particularly the urban ones, there were very few elevations marked; in such cases we measured ECPs from the contours on the map.

The elevations at the ECPs were then compared with the corresponding elevations from the new DEM. The comparison for a given ECP involved conversion of its UTM coordinates to a DEM line and pixel number and calculating the difference between the elevations of the closest DEM pixel and the ECP. The statistics for all ECPs (mean difference, standard deviation, minimum and maximum difference) were also computed.

The first column of Table 1 shows the results of the ECP evaluation of the DEM after editing. The results are quite good for the 30 m pixels, although the DEM elevations are on average 9 m too low. The analysis of the spatial distribution of differences also indicated that the differences tended to be negative towards the upper left (NW) corner of the image, and positive towards the SE corner.

**Table 1 ECP evaluation in metres after DEM editing steps**

| Statistic | Step editing | Polynomial correction | Final DEM |
|---|---|---|---|
| Average | -9.0 | -0.2 | 0.1 |
| Standard deviation | 15.9 | 11.9 | 11.1 |
| Minimum difference | -56.6 | -31.5 | -36.6 |
| Maximum difference | 34.5 | 34.3 | 34.7 |

### 3.4.4 *Polynomial DEM correction*

The apparent tilt and offset of the DEM mentioned in the previous section are partly attributed to geometric modelling approximations, and can also result from the variation in the satellite altitude across the scene which is in the range of 20 - 30 m and would introduce a tilt into the DEM of equivalent magnitude.

To compensate for these discrepancies, a second order polynomial correction was applied to the DEM values. The polynomial was derived by least squares approximation of the elevation differences between our DEM and ECPs. Then, the correction calculated for a given line/pixel from the two dimensional function was subtracted from the DEM value at that pixel. The correction was mostly planar. The ECP evaluation of the DEM after the polynomial correction is shown in the second column of Table 1. The correction brought the mean difference practically to zero, significantly reduced the standard deviation of the differences and made the minimum and maximum differences almost symmetric.

### 3.4.5 *Water editing*

During the matching of the two images, the pixels over water bodies usually do not produce successful matches. A water mask is created, which is a binary image with all water pixels set to one and all land pixels set to zero. The water mask is derived from one of the original images that has been median-filtered, by flagging all sufficiently dark pixels as water. The cutoff value can be inferred from the histogram of the DNs for the image.

With the water mask derived, our water editing package first identifies all pixels belonging to the same body of water, and then assigns to them a unique value, the water body number. The next program then calculates the mean elevation of every body of water and assigns it to all pixels. This is sufficient for the lakes; however, in the case of rivers it is also necessary to ensure their consistent flow. A river is divided into sections (*e.g.*, at rapids) and a constant elevation is assigned to each section. In this step the larger lakes are also set to the proper elevation.

### 3.4.6 *DEM filtering*

Filtering is the final operation of DEM editing. Filtering is designed to remove all discontinuities created in the previous editing steps, due mostly to the setting of water bodies to constant elevations. The filter used for the final run was a 9x9 moving average filter, with all pixels in the window evenly weighted. The results of the ECP evaluation are summarized in the last column of Table 1. Table 2 shows the statistics of the final DEM.

**Table 2 Final DEM statistics in metres**

| Statistic | Value |
|---|---|
| Average elevation | 103.5 |
| Minimum elevation | 41 |
| Maximum elevation | 364 |

## 3.5 UTM to geographic coordinates conversion

The contract required the delivery of the DEM data in the DTED format. The major difference between the Horler Information format and the DTED is the coordinate system used. Our DEM is stored in UTM coordinates, giving the advantage of square pixels. On the other hand the DTED format uses geographic coordinates, with either 3 arc seconds (Level 1 DTED) or 1 arc second (Level 2 DTED) nominal data spacing. In mid-latitudes this results in rectangular pixels,

with an aspect ratio of about 1.5 to 1. Also, the data are arranged into full degree arrays, with the size of 1201 rows by 1201 columns for Level 1 data, and 3601 by 3601 for Level 2. Finally, the data arrangement is different. In our software the values are stored by lines, starting from the top line, and with pixels running from west to east. In the DTED format the values are stored in columns, starting at the southwest corner of the 1 degree block.

All these differences meant that the conversion to the final format required several steps. The first step consisted of resampling of the DEM from UTM to geographical coordinates, using the cubic convolution resampling function. In this step an unprocessed frame surrounding our DEM was also removed. The resulting DEM had the following corner coordinates:

- Upper Left corner: 75°52'24"W, 45°35'06"N;

- Lower Right corner: 75°29'57"W, 45°19'18"N.

In the second step the resampled DEM was reformatted to the DTED format. In the process all undefined values in the 1° square were set to zero.

The above procedure was in fact performed twice. In the first instance the resolution of the original 30 m DEM was reduced to 90 m, and the resulting DEM was converted to the Level 1 (3") DTED format. The area with elevation data had 316 rows and 449 columns, and was offset from the SW corner of the 1° block (at 76°W, 45°N) by 153 columns and 387 rows. The file size of the full grid was 2,889,214 bytes.

In the second instance the original 30 m DEM was converted to the Level 2 (1") DTED. The area with the data had 948 rows and 1347 columns and was offset from the same SW corner by 459 columns and 1161 rows. The file size of the full 1° grid was 25,977,614 bytes.

The error of the UTM to DTED conversion was on the order of 10 cm.

### 3.6 Data transfer to ADES and demonstration

The Level 1 DEM in DTED format was successfully loaded into the ADES at Transport Canada. It was confirmed that the data supported the preparation of a contour map, 3-D terrain views and flight simulations.

The Level 2 DEM is nine times the data volume of the Level 1 data and is about 25 megabytes. The sheer data volume requires careful disk space management and has so far prevented the evaluation of the Level 2 DEM in ADES.

# 4 Feasibility Evaluation of Using SPOT Imagery in ADES

SPOT-derived DEMs and images have the potential to provide photo-realistic terrain views by draping the imagery over the DEM in oblique or perspective views. Horler Information has demonstrated this capability in-house. However, the ADES presently does not have the capability for raster image manipulation and display that would be necessary. It would be quite feasible to incorporate such capabilities into ADES. It seems likely that enhancements to ADES hardware and software are required to handle DTED Level 2 data.

Most systems for such terrain visualization applications, particularly simulation, use polygon displays because of the lower data volume and thus the ability to recompute to display sufficiently fast to create flight simulations. The polygon display creates cartoon-like images but, unfortunately, computer technology is not yet sufficiently advanced to support raster simulations on workstations at useful speeds. However, the use of satellite imagery permits a classification to be done of land cover type, from which polygon outlines, or linear or point features, can be extracted and an identifying attribute assigned to each polygon or feature. The database can contain attributes for each land cover type to control the visualization, such as parameters for texture, colour, brightness, and specular/diffuse reflectance.

The use of satellite imagery in ADES requires not only enhancing the image handling capabilities to be able to manipulate and display imagery, but also requires a suite of image processing capabilities for data preparation. The image processing tasks include all those described in the body of this report which can be summarized as:

- data input
- geometric correction
- point digitization
- radiometric enhancement and correction
- DEM generation
- interactive image display
- interactive image editing
- image classification
- vector and polygon extraction
- formatting and output.

Because of the large data volumes and the computer-intensive nature of image processing, it is suggested that these requirements would best be served by a dedicated companion system to ADES. This could be a workstation networked with ADES. Given this facility, it is expected that terrain databases could be prepared in one to a few days for each airport. The required system can be based on commercially available products and would require some integration and custom development.

# 5 Conclusions

1 Two digital elevation models of the Ottawa area were prepared by digital processing of SPOT stereo imagery. The DEMs corresponded to Level 1 and Level 2 NATO DTED formats. The Level 1 DEM was created by averaging pixels of the Level 2 data.

2 The standard deviation of the difference between the Level 2 DEM and 349 elevation control points read from 1: 25,000 topographic maps was 11.1 metres, equivalent to about one-third of a pixel.

3 The Level 1 DEM was successfully transfered to the ADES and used to generate a contour map, a 3-D terrain view and a simulated airport approach. Enhancements to ADES would be needed to handle the greater volume of Level 2 data as well as to handle raster imagery efficiently.

4 The use of SPOT imagery would allow the preparation of accurate and detailed terrain databases for virtually any area on demand. A dedicated image processing system is recommended for database preparation.

## Appendix A

## Coordinates of Elevation Control Points

Input ECP file name: verott.ecp
Output ECP file name: verott.lal
Report file name: verott.rep

ECP elevations are in feet.
UTM zone of ECPs: 18

| ECP | Northing | Easting | Feet | Latitude | Longitude | Metres |
|---|---|---|---|---|---|---|
| 1 | 5048200 | 432075 | 375.0 | 45.5859827248 | 75.8707208774 | 114.3 |
| 2 | 5047700 | 438632 | 553.0 | 45.5820923535 | 75.7866131922 | 168.6 |
| 3 | 5046550 | 438875 | 507.0 | 45.5717634906 | 75.7833547888 | 154.5 |
| 4 | 5045925 | 438925 | 542.0 | 45.5661427282 | 75.7826359416 | 165.2 |
| 5 | 5046537 | 436975 | 500.0 | 45.5714769205 | 75.8077003883 | 152.4 |
| 6 | 5045820 | 437345 | 649.0 | 45.5650572016 | 75.8028671615 | 197.8 |
| 7 | 5047110 | 435225 | 793.0 | 45.5764732269 | 75.8302012550 | 241.7 |
| 8 | 5044750 | 433030 | 838.0 | 45.5550251195 | 75.8580073437 | 255.4 |
| 9 | 5043910 | 441245 | 648.0 | 45.5482068740 | 75.7526671425 | 197.5 |
| 10 | 5047370 | 440810 | 714.0 | 45.5793110846 | 75.7586581633 | 217.6 |
| 11 | 5046125 | 446100 | 723.0 | 45.5685357283 | 75.6907222805 | 220.4 |
| 12 | 5045587 | 439700 | 690.0 | 45.5631682419 | 75.7726640372 | 210.3 |
| 13 | 5045562 | 433350 | 788.0 | 45.5623639229 | 75.8540187292 | 240.2 |
| 14 | 5044306 | 439312 | 691.0 | 45.5516051515 | 75.7774762630 | 210.6 |
| 15 | 5043975 | 435506 | 544.0 | 45.5482838375 | 75.8261864672 | 165.8 |
| 16 | 5043200 | 432706 | 735.0 | 45.5410437087 | 75.8619446533 | 224.0 |
| 17 | 5041943 | 435406 | 647.0 | 45.5299861663 | 75.8271991431 | 197.2 |
| 18 | 5041925 | 440000 | 569.0 | 45.5302350316 | 75.7683711109 | 173.4 |
| 19 | 5039970 | 432773 | 1166.0 | 45.5119797321 | 75.8606431381 | 355.4 |
| 20 | 5039693 | 433925 | 1073.0 | 45.5095968389 | 75.8458594684 | 327.1 |
| 21 | 5039550 | 440500 | 327.0 | 45.5089020414 | 75.7616801158 | 99.7 |
| 22 | 5047255 | 443070 | 749.0 | 45.5784647472 | 75.7296799903 | 228.3 |
| 23 | 5047362 | 445062 | 771.0 | 45.5795880191 | 75.7041622566 | 235.0 |
| 24 | 5047012 | 446581 | 745.0 | 45.5765562219 | 75.6846557637 | 227.1 |
| 25 | 5046975 | 449097 | 516.0 | 45.5764119195 | 75.6524072273 | 157.3 |
| 26 | 5045843 | 442572 | 652.0 | 45.5657153184 | 75.7358964078 | 198.7 |
| 27 | 5045150 | 445000 | 589.0 | 45.5596742212 | 75.7047078626 | 179.5 |
| 28 | 5045425 | 446587 | 531.0 | 45.5622729773 | 75.6844053719 | 161.8 |
| 29 | 5045500 | 448550 | 517.0 | 45.5630959424 | 75.6592621539 | 157.6 |
| 30 | 5044475 | 450425 | 358.0 | 45.5540065060 | 75.6351341349 | 109.1 |
| 31 | 5043662 | 442875 | 616.0 | 45.5461104491 | 75.7317591878 | 187.8 |
| 32 | 5043506 | 446881 | 366.0 | 45.5450235694 | 75.6804300179 | 111.6 |
| 33 | 5043450 | 448862 | 355.0 | 45.5446678717 | 75.6550501664 | 108.2 |

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|---|---|---|---|---|---|---|
| 34 | 5043137 | 450543 | 337.0 | 45.5419721373 | 75.6334871720 | 102.7 |
| 35 | 5042450 | 441737 | 453.0 | 45.5351076906 | 75.7461911814 | 138.1 |
| 36 | 5042531 | 445400 | 416.0 | 45.5361335431 | 75.6992907496 | 126.8 |
| 37 | 5042550 | 448025 | 354.0 | 45.5365054149 | 75.6656753634 | 107.9 |
| 38 | 5039522 | 445768 | 348.0 | 45.5090797919 | 75.6942447525 | 106.1 |
| 39 | 5047050 | 452656 | 581.0 | 45.5773383639 | 75.6068026254 | 177.1 |
| 40 | 5046793 | 455700 | 524.0 | 45.5752257794 | 75.5677667119 | 159.7 |
| 41 | 5047850 | 457350 | 595.0 | 45.5848426247 | 75.5467129565 | 181.4 |
| 42 | 5047712 | 460406 | 582.0 | 45.5837812888 | 75.5075297553 | 177.4 |
| 43 | 5045175 | 451675 | 465.0 | 45.5603948301 | 75.6191898058 | 141.7 |
| 44 | 5044420 | 454031 | 497.0 | 45.5537589926 | 75.5889329584 | 151.5 |
| 45 | 5044762 | 456631 | 424.0 | 45.5570041018 | 75.5556549568 | 129.2 |
| 46 | 5044975 | 459675 | 368.0 | 45.5591043092 | 75.5166736616 | 112.2 |
| 47 | 5042475 | 452075 | 352.0 | 45.5361208644 | 75.6138003372 | 107.3 |
| 48 | 5041937 | 455550 | 307.0 | 45.5315089632 | 75.5692476536 | 93.6 |
| 49 | 5041912 | 457525 | 282.0 | 45.5314071862 | 75.5439538784 | 86.0 |
| 50 | 5041525 | 459237 | 189.0 | 45.5280261841 | 75.5219979540 | 57.6 |
| 51 | 5039268 | 452850 | 193.0 | 45.5073086391 | 75.6035663517 | 58.8 |
| 52 | 5040668 | 455150 | 209.0 | 45.5200614266 | 75.5742537592 | 63.7 |
| 53 | 5040722 | 457175 | 184.0 | 45.5206748686 | 75.5483318592 | 56.1 |
| 54 | 5040175 | 460525 | 144.0 | 45.5159492672 | 75.5053960903 | 43.9 |
| 55 | 5037475 | 432510 | 1129.0 | 45.4894988835 | 75.8636662885 | 344.1 |
| 56 | 5038305 | 437395 | 377.0 | 45.4974247015 | 75.8012655031 | 114.9 |
| 57 | 5038331 | 433768 | 1143.0 | 45.4973236576 | 75.8476850902 | 348.4 |
| 58 | 5037250 | 434531 | 807.0 | 45.4876664409 | 75.8377764539 | 246.0 |
| 59 | 5036727 | 437450 | 364.0 | 45.4832271091 | 75.8003604574 | 110.9 |
| 60 | 5037200 | 440018 | 334.0 | 45.4877098100 | 75.7675623801 | 101.8 |
| 61 | 5035300 | 432162 | 366.0 | 45.4698896977 | 75.8678185443 | 111.6 |
| 62 | 5035110 | 436325 | 697.0 | 45.4685718143 | 75.8145442730 | 212.4 |
| 63 | 5034206 | 434387 | 334.0 | 45.4602560801 | 75.8392122147 | 101.8 |
| 64 | 5035743 | 439847 | 324.0 | 45.4745814797 | 75.7695718378 | 98.8 |
| 65 | 5032700 | 432887 | 425.0 | 45.4465591217 | 75.8581899631 | 129.5 |
| 66 | 5031231 | 437275 | 328.0 | 45.4337453003 | 75.8018979674 | 100.0 |
| 67 | 5031056 | 438906 | 293.0 | 45.4323146984 | 75.7810269517 | 89.3 |
| 68 | 5030731 | 432475 | 465.0 | 45.4287978770 | 75.8631874555 | 141.7 |
| 69 | 5030250 | 434556 | 385.0 | 45.4246666369 | 75.8365245098 | 117.3 |
| 70 | 5029962 | 438656 | 293.0 | 45.4224462856 | 75.7840863196 | 89.3 |
| 71 | 5038431 | 442600 | 225.0 | 45.4990066262 | 75.7346685420 | 68.6 |
| 72 | 5037145 | 444087 | 202.0 | 45.4875527958 | 75.7154912068 | 61.6 |
| 73 | 5036850 | 447031 | 182.0 | 45.4851273819 | 75.6777891693 | 55.5 |
| 74 | 5038287 | 449487 | 317.0 | 45.4982434528 | 75.6465123198 | 96.6 |
| 75 | 5035487 | 442781 | 148.0 | 45.4725240726 | 75.7320088256 | 45.1 |
| 76 | 5034500 | 444412 | 147.0 | 45.4637723327 | 75.7110332083 | 44.8 |
| 77 | 5033950 | 445797 | 137.0 | 45.4589309048 | 75.6932581467 | 41.8 |
| 78 | 5035131 | 449872 | 147.0 | 45.4698651543 | 75.6412626864 | 44.8 |
| 79 | 5033620 | 443050 | 154.0 | 45.4557420890 | 75.7283513382 | 46.9 |
| 80 | 5032570 | 446531 | 247.0 | 45.4465666230 | 75.6837208382 | 75.3 |
| 81 | 5030400 | 442725 | 192.0 | 45.4267337175 | 75.7321325837 | 58.5 |
| 82 | 5032656 | 444012 | 168.0 | 45.4471433254 | 75.7159392091 | 51.2 |
| 83 | 5033225 | 444725 | 151.0 | 45.4523214449 | 75.7068864879 | 46.0 |
| 84 | 5030862 | 448050 | 190.0 | 45.4313080578 | 75.6641179860 | 57.9 |

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|---|---|---|---|---|---|---|
| 85 | 5027720 | 443925 | 210.0 | 45.4027093182 | 75.7164893925 | 64.0 |
| 86 | 5027500 | 448900 | 260.0 | 45.4011102067 | 75.6529036670 | 79.2 |
| 87 | 5036087 | 451781 | 141.0 | 45.4786043279 | 75.6169371278 | 43.0 |
| 88 | 5038237 | 457462 | 138.0 | 45.4983255194 | 75.5444415964 | 42.1 |
| 89 | 5035406 | 455850 | 166.0 | 45.4727441000 | 75.5648178084 | 50.6 |
| 90 | 5035225 | 460422 | 289.0 | 45.4713891839 | 75.5063153464 | 88.1 |
| 91 | 5030572 | 451556 | 237.0 | 45.4289496301 | 75.6192721966 | 72.2 |
| 92 | 5030825 | 453580 | 225.0 | 45.4313641840 | 75.5934241698 | 68.6 |
| 93 | 5030615 | 457125 | 237.0 | 45.4297004502 | 75.5480894635 | 72.2 |
| 94 | 5033781 | 460625 | 287.0 | 45.4584033562 | 75.5036027618 | 87.5 |
| 95 | 5032800 | 458795 | 303.0 | 45.4494678918 | 75.5269250908 | 92.4 |
| 96 | 5031731 | 460412 | 285.0 | 45.4399394096 | 75.5061618448 | 86.9 |
| 97 | 5028175 | 456662 | 259.0 | 45.4077096814 | 75.5537931847 | 78.9 |
| 98 | 5028775 | 459462 | 227.0 | 45.4132781373 | 75.5180643698 | 69.2 |
| 99 | 5025137 | 451381 | 278.0 | 45.3800180129 | 75.6209729532 | 84.7 |
| 100 | 5026647 | 455172 | 259.0 | 45.3938623947 | 75.5726931969 | 78.9 |
| 101 | 5025556 | 459406 | 255.0 | 45.3843006973 | 75.5185149340 | 77.7 |
| 102 | 5026625 | 460420 | 221.0 | 45.3939808565 | 75.5056492169 | 67.4 |
| 103 | 5036568 | 461300 | 288.0 | 45.4835266255 | 75.4951895198 | 87.8 |
| 104 | 5028406 | 461225 | 226.0 | 45.4100567356 | 75.4955055432 | 68.9 |
| 105 | 5024625 | 432795 | 213.0 | 45.3738726138 | 75.8582647834 | 64.9 |
| 106 | 5022175 | 433806 | 206.0 | 45.3519178290 | 75.8450265309 | 62.8 |
| 107 | 5020550 | 435031 | 224.0 | 45.3374066367 | 75.8291764073 | 68.3 |
| 108 | 5021977 | 436625 | 215.0 | 45.3503962960 | 75.8090177323 | 65.5 |
| 109 | 5023355 | 438550 | 250.0 | 45.3629705124 | 75.7846177597 | 76.2 |
| 110 | 5023255 | 440518 | 270.0 | 45.3622403007 | 75.7594797755 | 82.3 |
| 111 | 5019295 | 432012 | 379.0 | 45.3258248807 | 75.8675300265 | 115.5 |
| 112 | 5019372 | 433797 | 279.0 | 45.3266886455 | 75.8447661669 | 85.0 |
| 113 | 5019000 | 436225 | 318.0 | 45.3235653767 | 75.8137395661 | 96.9 |
| 114 | 5019335 | 439481 | 308.0 | 45.3268690294 | 75.7722393701 | 93.9 |
| 115 | 5023760 | 441897 | 325.0 | 45.3669013536 | 75.7419333033 | 99.1 |
| 116 | 5023856 | 442952 | 303.0 | 45.3678521316 | 75.7284739120 | 92.4 |
| 117 | 5023445 | 444375 | 283.0 | 45.3642672817 | 75.7102580528 | 86.3 |
| 118 | 5022681 | 447831 | 283.0 | 45.3576565458 | 75.6660518882 | 86.3 |
| 119 | 5023718 | 449850 | 272.0 | 45.3671378403 | 75.6403818613 | 82.9 |
| 120 | 5021730 | 442706 | 305.0 | 45.3486965847 | 75.7313683901 | 93.0 |
| 121 | 5020972 | 444450 | 285.0 | 45.3420143943 | 75.7090224772 | 86.9 |
| 122 | 5021662 | 446500 | 318.0 | 45.3483843798 | 75.6829335071 | 96.9 |
| 123 | 5019687 | 442025 | 287.0 | 45.3302521518 | 75.7398212415 | 87.5 |
| 124 | 5018697 | 447425 | 374.0 | 45.3217668661 | 75.6708114420 | 114.0 |
| 125 | 5018475 | 450727 | 327.0 | 45.3200083276 | 75.6286613188 | 99.7 |
| 126 | 5024750 | 451993 | 276.0 | 45.3765769020 | 75.6131191560 | 84.1 |
| 127 | 5024075 | 454402 | 267.0 | 45.3706622786 | 75.5822920127 | 81.4 |
| 128 | 5023550 | 457180 | 267.0 | 45.3661121005 | 75.5467727621 | 81.4 |
| 129 | 5024156 | 458647 | 252.0 | 45.3716548591 | 75.5280920648 | 76.8 |
| 130 | 5021875 | 453262 | 305.0 | 45.3507850818 | 75.5966410050 | 93.0 |
| 131 | 5022180 | 455910 | 266.0 | 45.3537019649 | 75.5628664614 | 81.1 |
| 132 | 5021595 | 458697 | 259.0 | 45.3486061437 | 75.5272394391 | 78.9 |
| 133 | 5022956 | 459493 | 261.0 | 45.3609030447 | 75.5171903654 | 79.6 |
| 134 | 5020362 | 451230 | 314.0 | 45.3370282475 | 75.6224300503 | 95.7 |
| 135 | 5018605 | 456150 | 278.0 | 45.3215383451 | 75.5594857166 | 84.7 |

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|---|---|---|---|---|---|---|
| 136 | 5019345 | 439800 | 266.0 | 45.3284178050 | 75.5129771416 | 81.1 |
| 137 | 5022887 | 460905 | 262.0 | 45.3603621815 | 75.4991572935 | 79.9 |
| 138 | 5020856 | 460637 | 263.0 | 45.3420659619 | 75.5024171649 | 80.2 |
| 139 | 5045390 | 432185 | 799.0 | 45.5607033389 | 75.8689208595 | 243.5 |
| 140 | 5045300 | 437280 | 599.0 | 45.5603712347 | 75.8036332653 | 182.6 |
| 141 | 5043405 | 433530 | 685.0 | 45.5429678858 | 75.8514193644 | 208.8 |
| 142 | 5043945 | 434595 | 790.0 | 45.5479288340 | 75.8378513759 | 240.8 |
| 143 | 5043580 | 434375 | 768.0 | 45.5446230725 | 75.8406203494 | 234.1 |
| 144 | 5043115 | 433995 | 770.0 | 45.5404020801 | 75.8454246786 | 234.7 |
| 145 | 5043240 | 437890 | 563.0 | 45.5418854412 | 75.7955564569 | 171.6 |
| 146 | 5043980 | 438205 | 590.0 | 45.5485736663 | 75.7916155398 | 179.8 |
| 147 | 5043790 | 440055 | 595.0 | 45.5470253782 | 75.7678952862 | 181.4 |
| 148 | 5043105 | 440635 | 548.0 | 45.5409098515 | 75.7603830302 | 167.0 |
| 149 | 5043440 | 441225 | 620.0 | 45.5439750226 | 75.7528668547 | 189.0 |
| 150 | 5042400 | 432055 | 617.0 | 45.5337804083 | 75.8701710485 | 188.1 |
| 151 | 5040225 | 432255 | 1087.0 | 45.5142246141 | 75.8673090883 | 331.3 |
| 152 | 5040370 | 434710 | 673.0 | 45.5157639574 | 75.8359015696 | 205.1 |
| 153 | 5041630 | 435500 | 638.0 | 45.5271778091 | 75.8259542609 | 194.5 |
| 154 | 5040205 | 435385 | 589.0 | 45.5143418300 | 75.8272387628 | 179.5 |
| 155 | 5041895 | 436020 | 641.0 | 45.5296108230 | 75.8193307207 | 195.4 |
| 156 | 5041380 | 436325 | 608.0 | 45.5250036459 | 75.8153583068 | 185.3 |
| 157 | 5040720 | 437145 | 604.0 | 45.5191379291 | 75.8047745612 | 184.1 |
| 158 | 5040255 | 437685 | 497.0 | 45.5150012912 | 75.7978021140 | 151.5 |
| 159 | 5040795 | 438070 | 470.0 | 45.5198957759 | 75.7929418009 | 143.3 |
| 160 | 5042640 | 438680 | 596.0 | 45.5365552910 | 75.7853632603 | 181.7 |
| 161 | 5042935 | 439170 | 623.0 | 45.5392533548 | 75.7791247813 | 189.9 |
| 162 | 5042380 | 441245 | 534.0 | 45.5344363307 | 75.7524834206 | 162.8 |
| 163 | 5041450 | 440750 | 543.0 | 45.5260240597 | 75.7587098473 | 165.5 |
| 164 | 5040625 | 440775 | 546.0 | 45.5186008773 | 75.7582899864 | 166.4 |
| 165 | 5039915 | 435780 | 514.0 | 45.5117682674 | 75.8221442640 | 156.7 |
| 166 | 5038995 | 436020 | 670.0 | 45.5035100949 | 75.8189520173 | 204.2 |
| 167 | 5039670 | 437940 | 545.0 | 45.5097588628 | 75.7944636497 | 166.1 |
| 168 | 5039930 | 438995 | 439.0 | 45.5121920840 | 75.7809916628 | 133.8 |
| 169 | 5046970 | 441505 | 726.0 | 45.5757697754 | 75.7497029770 | 221.3 |
| 170 | 5046345 | 441955 | 717.0 | 45.5701822785 | 75.7438617635 | 218.5 |
| 171 | 5046575 | 442925 | 737.0 | 45.5723326275 | 75.7314588619 | 224.6 |
| 172 | 5046540 | 444405 | 646.0 | 45.5721374883 | 75.7124890682 | 196.9 |
| 173 | 5046545 | 446155 | 748.0 | 45.5723201694 | 75.6900638033 | 228.0 |
| 174 | 5046425 | 448105 | 547.0 | 45.5713883405 | 75.6650620811 | 166.7 |
| 175 | 5047450 | 448405 | 610.0 | 45.5806361477 | 75.6613259608 | 185.9 |
| 176 | 5047705 | 450345 | 632.0 | 45.5830725254 | 75.6364872557 | 192.6 |
| 177 | 5044305 | 442955 | 662.0 | 45.5519042581 | 75.7308094833 | 201.8 |
| 178 | 5045520 | 443720 | 561.0 | 45.5629020137 | 75.7211496450 | 171.0 |
| 179 | 5044820 | 444430 | 569.0 | 45.5566587987 | 75.7119731218 | 173.4 |
| 180 | 5044135 | 444370 | 546.0 | 45.5504887201 | 75.7126638629 | 166.4 |
| 181 | 5045905 | 444825 | 596.0 | 45.5664556777 | 75.7070351769 | 181.7 |
| 182 | 5044450 | 445305 | 591.0 | 45.5533979583 | 75.7007219222 | 180.1 |
| 183 | 5044845 | 446700 | 549.0 | 45.5570613744 | 75.6828943133 | 167.3 |
| 184 | 5045840 | 449380 | 467.0 | 45.5662170012 | 75.6486627368 | 142.3 |
| 185 | 5045770 | 450450 | 534.0 | 45.5656639982 | 75.6349451349 | 162.8 |
| 186 | 5044825 | 450845 | 380.0 | 45.5571864945 | 75.6297887874 | 115.8 |

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|---|---|---|---|---|---|---|
| 187 | 5043775 | 443520 | 611.0 | 45.5471801230 | 75.7235105889 | 186.2 |
| 188 | 5043980 | 446180 | 443.0 | 45.5492359535 | 75.6894610088 | 135.0 |
| 189 | 5042250 | 452095 | 323.0 | 45.5340970997 | 75.6135221799 | 98.5 |
| 190 | 5041420 | 445530 | 399.0 | 45.5261441891 | 75.6975022828 | 121.6 |
| 191 | 5040795 | 446915 | 347.0 | 45.5206257754 | 75.6797005333 | 105.8 |
| 192 | 5041725 | 448340 | 343.0 | 45.5291034037 | 75.6615541745 | 104.5 |
| 193 | 5040005 | 448405 | 335.0 | 45.5136272487 | 75.6605406661 | 102.1 |
| 194 | 5040995 | 450580 | 323.0 | 45.5226954854 | 75.6327970293 | 98.5 |
| 195 | 5038995 | 441925 | 314.0 | 45.5040269822 | 75.7433740101 | 95.7 |
| 196 | 5039470 | 443325 | 344.0 | 45.5084174182 | 75.7255100544 | 104.9 |
| 197 | 5038750 | 443900 | 232.0 | 45.5019835838 | 75.7180675347 | 70.7 |
| 198 | 5038830 | 444890 | 285.0 | 45.5027825789 | 75.7054057226 | 86.9 |
| 199 | 5039090 | 447040 | 335.0 | 45.5052893549 | 75.6779158772 | 102.1 |
| 200 | 5039165 | 449290 | 337.0 | 45.5061316961 | 75.6491243539 | 102.7 |
| 201 | 5039705 | 449870 | 328.0 | 45.5110339797 | 75.6417556395 | 100.0 |
| 202 | 5038910 | 450895 | 298.0 | 45.5039514340 | 75.6285549261 | 90.8 |
| 203 | 5047805 | 451595 | 363.0 | 45.5840607289 | 75.6204753915 | 110.6 |
| 204 | 5047204 | 453520 | 685.0 | 45.5787827399 | 75.5957441027 | 208.8 |
| 205 | 5047208 | 458880 | 535.0 | 45.5791563625 | 75.5270472934 | 163.1 |
| 206 | 5046255 | 451420 | 506.0 | 45.5700976808 | 75.6225642986 | 154.2 |
| 207 | 5046240 | 452275 | 540.0 | 45.5700218610 | 75.6116064390 | 164.6 |
| 208 | 5046920 | 452705 | 620.0 | 45.5761716239 | 75.6061620443 | 189.0 |
| 209 | 5046535 | 454575 | 643.0 | 45.5728310489 | 75.5821604326 | 196.0 |
| 210 | 5046610 | 459155 | 483.0 | 45.5737901515 | 75.5234726733 | 147.2 |
| 211 | 5045820 | 452825 | 467.0 | 45.5662791331 | 75.6045179138 | 142.3 |
| 212 | 5045375 | 453175 | 465.0 | 45.5622975116 | 75.5999904956 | 141.7 |
| 213 | 5045350 | 454050 | 465.0 | 45.5621308334 | 75.5887769656 | 141.7 |
| 214 | 5045755 | 455120 | 513.0 | 45.5658459359 | 75.5751044956 | 156.4 |
| 215 | 5045150 | 455970 | 529.0 | 45.5604548526 | 75.5641583978 | 161.2 |
| 216 | 5045490 | 456675 | 396.0 | 45.5635593372 | 75.5551557698 | 120.7 |
| 217 | 5045090 | 457383 | 468.0 | 45.5600027896 | 75.5460491755 | 142.6 |
| 218 | 5045790 | 458175 | 415.0 | 45.5663513392 | 75.5359616816 | 126.5 |
| 219 | 5045400 | 458200 | 379.0 | 45.5628425682 | 75.5356079779 | 115.5 |
| 220 | 5044875 | 451370 | 436.0 | 45.5576734092 | 75.6230677045 | 132.9 |
| 221 | 5044600 | 452900 | 468.0 | 45.5553034811 | 75.6034393313 | 142.6 |
| 222 | 5044380 | 454795 | 485.0 | 45.5534490095 | 75.5791417640 | 147.8 |
| 223 | 5044030 | 458345 | 385.0 | 45.5505202820 | 75.5336333625 | 117.3 |
| 224 | 5043315 | 451795 | 389.0 | 45.5436620528 | 75.6174689831 | 118.6 |
| 225 | 5043415 | 452960 | 416.0 | 45.5446418041 | 75.6025566859 | 126.8 |
| 226 | 5043580 | 455450 | 378.0 | 45.5462907072 | 75.5706778120 | 115.2 |
| 227 | 5043550 | 456775 | 337.0 | 45.5461042184 | 75.5537029506 | 102.7 |
| 228 | 5043520 | 458385 | 326.0 | 45.5459323016 | 75.5330775615 | 99.4 |
| 229 | 5043180 | 460255 | 309.0 | 45.5429813130 | 75.5090966899 | 94.2 |
| 230 | 5042725 | 456865 | 307.0 | 45.5386842135 | 75.5524773898 | 93.6 |
| 231 | 5042390 | 459095 | 290.0 | 45.5358035271 | 75.5238885626 | 88.4 |
| 232 | 5042055 | 460750 | 207.0 | 45.5328835046 | 75.5026662161 | 63.1 |
| 233 | 5041355 | 451625 | 312.0 | 45.5260090538 | 75.6194527120 | 95.1 |
| 234 | 5041270 | 454140 | 294.0 | 45.5254140987 | 75.5872413640 | 89.6 |
| 235 | 5040425 | 451825 | 304.0 | 45.5176523165 | 75.6168003450 | 92.7 |
| 236 | 5040915 | 453225 | 286.0 | 45.5221580273 | 75.5989234760 | 87.2 |
| 237 | 5040870 | 458715 | 182.0 | 45.5220999345 | 75.5286270149 | 55.5 |

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|---|---|---|---|---|---|---|
| 238 | 5041025 | 460655 | 181.0 | 45.5236073150 | 75.5038000457 | 55.2 |
| 239 | 5039330 | 451445 | 215.0 | 45.5077702327 | 75.6215568241 | 65.5 |
| 240 | 5039875 | 453915 | 189.0 | 45.5128432879 | 75.5899911184 | 57.6 |
| 241 | 5039925 | 454045 | 190.0 | 45.5133019070 | 75.5883316051 | 57.9 |
| 242 | 5039130 | 454130 | 194.0 | 45.5061519421 | 75.5871690583 | 59.1 |
| 243 | 5039170 | 458375 | 147.0 | 45.5067783687 | 75.5328358827 | 44.8 |
| 244 | 5039850 | 457050 | 156.0 | 45.5128185145 | 75.5498558417 | 47.5 |
| 245 | 5039375 | 460125 | 142.0 | 45.5087258372 | 75.5104519661 | 43.3 |
| 246 | 5038725 | 451225 | 240.0 | 45.5023094773 | 75.6243127015 | 73.2 |
| 247 | 5038650 | 451885 | 180.0 | 45.5016802859 | 75.6158579352 | 54.9 |
| 248 | 5038680 | 455270 | 165.0 | 45.5021756873 | 75.5725359223 | 50.3 |
| 249 | 5038720 | 456405 | 155.0 | 45.5026076103 | 75.5580123868 | 47.2 |
| 250 | 5038850 | 457115 | 153.0 | 45.5038217453 | 75.5489362404 | 46.6 |
| 251 | 5038850 | 458950 | 141.0 | 45.5039322061 | 75.5254489047 | 43.0 |
| 252 | 5038305 | 438875 | 351.0 | 45.4975560008 | 75.7823251585 | 107.0 |
| 253 | 5038440 | 440395 | 187.0 | 45.4989026342 | 75.7628891864 | 57.0 |
| 254 | 5035245 | 433540 | 373.0 | 45.4695272482 | 75.8501849922 | 113.7 |
| 255 | 5034945 | 435650 | 590.0 | 45.4670248620 | 75.8231565095 | 179.8 |
| 256 | 5032945 | 434705 | 408.0 | 45.4489364938 | 75.8349778155 | 124.4 |
| 257 | 5033920 | 436950 | 377.0 | 45.4579181130 | 75.8063972282 | 114.9 |
| 258 | 5030245 | 433425 | 450.0 | 45.4245148465 | 75.8509790184 | 137.2 |
| 259 | 5031580 | 435980 | 380.0 | 45.4367690078 | 75.8184974191 | 115.8 |
| 260 | 5031745 | 440320 | 309.0 | 45.4386382159 | 75.7630355500 | 94.2 |
| 261 | 5030905 | 440955 | 246.0 | 45.4311317242 | 75.7548167039 | 75.0 |
| 262 | 5028685 | 435035 | 347.0 | 45.4106257115 | 75.8301959999 | 105.8 |
| 263 | 5029930 | 436230 | 322.0 | 45.4219412072 | 75.8150877082 | 98.1 |
| 264 | 5028715 | 437875 | 292.0 | 45.4111537428 | 75.7939106469 | 89.0 |
| 265 | 5028910 | 440205 | 194.0 | 45.4131119235 | 75.7641613890 | 59.1 |
| 266 | 5028325 | 440700 | 198.0 | 45.4078887455 | 75.7577655904 | 60.4 |
| 267 | 5027210 | 433640 | 280.0 | 45.3972192130 | 75.8478223367 | 85.3 |
| 268 | 5025805 | 436395 | 207.0 | 45.3848293950 | 75.8124466029 | 63.1 |
| 269 | 5025995 | 436995 | 204.0 | 45.3865937446 | 75.8048076451 | 62.2 |
| 270 | 5037620 | 441680 | 220.0 | 45.4916309293 | 75.7463462889 | 67.1 |
| 271 | 5036995 | 442670 | 306.0 | 45.4860877076 | 75.7336048571 | 93.3 |
| 272 | 5037155 | 445650 | 184.0 | 45.4877663302 | 75.6954928760 | 56.1 |
| 273 | 5038450 | 447630 | 324.0 | 45.4995735559 | 75.6702957301 | 98.8 |
| 274 | 5038275 | 448770 | 317.0 | 45.4980831379 | 75.6556872977 | 96.6 |
| 275 | 5036150 | 441470 | 195.0 | 45.4783826729 | 75.7488581976 | 59.4 |
| 276 | 5035910 | 442625 | 151.0 | 45.4763184774 | 75.7340538124 | 46.0 |
| 277 | 5036075 | 443250 | 205.0 | 45.4778546676 | 75.7260773060 | 62.5 |
| 278 | 5036285 | 444040 | 183.0 | 45.4798085789 | 75.7159945368 | 55.8 |
| 279 | 5035205 | 445690 | 172.0 | 45.4702183349 | 75.6947653179 | 52.4 |
| 280 | 5035795 | 447420 | 173.0 | 45.4756611666 | 75.6726988798 | 52.7 |
| 281 | 5035200 | 448325 | 153.0 | 45.4703733847 | 75.6610586453 | 46.6 |
| 282 | 5036190 | 448445 | 174.0 | 45.4792928939 | 75.6596275813 | 53.0 |
| 283 | 5034630 | 441950 | 181.0 | 45.4647420288 | 75.7425377198 | 55.2 |
| 284 | 5034525 | 443375 | 154.0 | 45.4639140084 | 75.7242994320 | 46.9 |
| 285 | 5033775 | 445320 | 158.0 | 45.4573186108 | 75.6993390656 | 48.2 |
| 286 | 5030540 | 441405 | 253.0 | 45.4278843967 | 75.7490210579 | 77.1 |
| 287 | 5030375 | 445365 | 154.0 | 45.4267200195 | 75.6983859059 | 46.9 |
| 288 | 5029855 | 441870 | 198.0 | 45.4217578359 | 75.7429965755 | 60.4 |

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|---|---|---|---|---|---|---|
| 289 | 5027950 | 442405 | 211.0 | 45.4046559806 | 75.7359362384 | 64.3 |
| 290 | 5036616 | 449425 | 170.0 | 45.4831988917 | 75.6471335423 | 51.8 |
| 291 | 5032855 | 446800 | 240.0 | 45.4491523451 | 75.6803121512 | 73.2 |
| 292 | 5031420 | 450600 | 240.0 | 45.4365153638 | 75.6315773804 | 73.2 |
| 293 | 5031110 | 448425 | 220.0 | 45.4335680061 | 75.6593503763 | 67.1 |
| 294 | 5030135 | 449080 | 210.0 | 45.4248403238 | 75.6508763357 | 64.0 |
| 295 | 5031780 | 441995 | 260.0 | 45.4390942863 | 75.7416258826 | 79.2 |
| 296 | 5030455 | 443710 | 220.0 | 45.4273087606 | 75.7195488623 | 67.1 |
| 297 | 5030620 | 446555 | 220.0 | 45.4290171778 | 75.6832021275 | 67.1 |
| 298 | 5029130 | 444925 | 240.0 | 45.4154796896 | 75.7038706397 | 73.2 |
| 299 | 5028995 | 446995 | 190.0 | 45.4144245541 | 75.6774029524 | 57.9 |
| 300 | 5027480 | 445570 | 230.0 | 45.4006790643 | 75.6954457450 | 70.1 |
| 301 | 5025855 | 442945 | 260.0 | 45.3858438946 | 75.7287943804 | 79.2 |
| 302 | 5026430 | 448230 | 300.0 | 45.3914301350 | 75.6613513217 | 91.4 |
| 303 | 5027355 | 450915 | 250.0 | 45.3999493520 | 75.6271451971 | 76.2 |
| 304 | 5025055 | 450620 | 280.0 | 45.3792266877 | 75.6306838256 | 85.3 |
| 305 | 5038355 | 452475 | 186.0 | 45.4990655479 | 75.6082779473 | 56.7 |
| 306 | 5035270 | 457750 | 179.0 | 45.4716375910 | 75.5405002256 | 54.6 |
| 307 | 5024825 | 455350 | 255.0 | 45.3774740698 | 75.5702543883 | 77.7 |
| 308 | 5026570 | 452390 | 254.0 | 45.3929855995 | 75.6082248190 | 77.4 |
| 309 | 5036675 | 460430 | 195.0 | 45.4844409169 | 75.5063298817 | 59.4 |
| 310 | 5032545 | 453000 | 280.0 | 45.4468067994 | 75.6010027001 | 85.3 |
| 311 | 5034340 | 452000 | 170.0 | 45.4628951552 | 75.6139645520 | 51.8 |
| 312 | 5034000 | 455200 | 170.0 | 45.4600475518 | 75.5730047157 | 51.8 |
| 313 | 5032705 | 458000 | 280.0 | 45.4485654571 | 75.5370829046 | 85.3 |
| 314 | 5029000 | 457540 | 220.0 | 45.4151892997 | 75.5426453075 | 67.1 |
| 315 | 5029405 | 452000 | 220.0 | 45.4184763224 | 75.6134829808 | 67.1 |
| 316 | 5037320 | 453000 | 180.0 | 45.4897853965 | 75.6014596131 | 54.9 |
| 317 | 5028205 | 455000 | 220.0 | 45.4078747641 | 75.5750326798 | 67.1 |
| 318 | 5027349 | 454000 | 210.0 | 45.4001049659 | 75.5877306184 | 64.0 |
| 319 | 5024845 | 452000 | 270.0 | 45.3774324654 | 75.6130390004 | 82.3 |
| 320 | 5031030 | 455000 | 240.0 | 45.4333022268 | 75.5752908498 | 73.2 |
| 321 | 5022480 | 436565 | 198.0 | 45.3549181370 | 75.8098481572 | 60.4 |
| 322 | 5023650 | 437570 | 205.0 | 45.3655390311 | 75.7971668674 | 62.5 |
| 323 | 5021630 | 432330 | 218.0 | 45.3468716477 | 75.8637922654 | 66.4 |
| 324 | 5021275 | 432820 | 219.0 | 45.3437236232 | 75.8574899917 | 66.8 |
| 325 | 5020450 | 433330 | 236.0 | 45.3363469284 | 75.8508698140 | 71.9 |
| 326 | 5024150 | 445395 | 253.0 | 45.3706930516 | 75.6973129358 | 77.1 |
| 327 | 5022505 | 443580 | 296.0 | 45.3557430396 | 75.7203009937 | 90.2 |
| 328 | 5021495 | 445080 | 272.0 | 45.3467714318 | 75.7010400655 | 82.9 |
| 329 | 5022330 | 449400 | 297.0 | 45.3546123015 | 75.6459855095 | 90.5 |
| 330 | 5019125 | 443675 | 300.0 | 45.3253281655 | 75.7187032439 | 91.4 |
| 331 | 5020030 | 445750 | 343.0 | 45.3336374373 | 75.6923275921 | 104.5 |
| 332 | 5020630 | 447405 | 329.0 | 45.3391640133 | 75.6712720988 | 100.3 |
| 333 | 5020745 | 449210 | 326.0 | 45.3403321847 | 75.6482481313 | 99.4 |
| 334 | 5020045 | 449275 | 325.0 | 45.3340362714 | 75.6473467752 | 99.1 |
| 335 | 5019780 | 450870 | 326.0 | 45.3317645793 | 75.6269664896 | 99.4 |
| 336 | 5023070 | 455995 | 276.0 | 45.3617181912 | 75.5618606524 | 84.1 |
| 337 | 5023095 | 456375 | 268.0 | 45.3619669803 | 75.5570112104 | 81.7 |
| 338 | 5021870 | 457720 | 268.0 | 45.3510231786 | 75.5397339765 | 81.7 |
| 339 | 5021280 | 457115 | 265.0 | 45.3456758135 | 75.5474056855 | 80.8 |

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|---|---|---|---|---|---|---|
| 340 | 5022580 | 457255 | 256.0 | 45.3573857001 | 75.5457311792 | 78.0 |
| 341 | 5022750 | 458150 | 266.0 | 45.3589699004 | 75.5343194995 | 81.1 |
| 342 | 5021350 | 459485 | 262.0 | 45.3464468705 | 75.5171608269 | 79.9 |
| 343 | 5021425 | 460521 | 264.0 | 45.3471810648 | 75.5039431340 | 80.5 |
| 344 | 5019450 | 455330 | 289.0 | 45.3290924881 | 75.5700239217 | 88.1 |
| 345 | 5020400 | 456270 | 283.0 | 45.3377027089 | 75.5581133521 | 86.3 |
| 346 | 5019150 | 457265 | 276.0 | 45.3265127314 | 75.5453070572 | 84.1 |
| 347 | 5019830 | 458745 | 267.0 | 45.3327220762 | 75.5264794805 | 81.4 |
| 348 | 5020250 | 459430 | 265.0 | 45.3365424966 | 75.5177726003 | 80.8 |
| 349 | 5020000 | 460550 | 266.0 | 45.3343561219 | 75.5034592788 | 81.1 |